

## **Holistic Engineering: A Concept Exploration in a Cross-Disciplinary Project Course Experience**

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Deskins has testified before the United States Senate, the United States House of Representatives, and the West Virginia Legislature. He has delivered more than 100 speeches to business, government, and community groups and his quotes have appeared in numerous media outlets such as The New York Times, The Wall Street Journal, The Washington Post, Bloomberg, CNBC, National Public Radio, and PBS. He has served as principal investigator or co-principal investigator on more than \$2 million in funded research.

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# Holistic Engineering: A Concept Exploration in a Cross-Disciplinary Project Course Experience

## Abstract

Holistic engineering is an approach to the engineering profession, rather than an engineering discipline such as civil, electrical, or mechanical engineering. It is inspired by the realization that traditional engineering does not adequately harness professional skills in its problem-solving repertoire. Holistic engineering asks engineers to look outward, beyond the fields of math and science, in search of solutions to entire problems. While engineering graduates are well prepared in the technical aspects of the engineering profession, they lack non-technical professional skills (e.g., strategic communication, social science perspective of engineering problems, and others) that can help them think through diverse social aspects posed by current complex engineering grand challenges.

In this paper, we review the concept and origins of holistic engineering and we present an application of this concept in a Holistic Engineering Project Course (HEPC) developed as part of a National Science Foundation (NSF) grant. HEPC is developed in such a way that engineering students work with social science students on a complex and open-ended engineering grand challenge problem. We hypothesize that such collaborations can significantly improve the professional formation of well-rounded, and effective engineers. The paper also draws lessons learned from the first offering of the course, titled *Technology Innovations: Engineering, Economics, and Public Relations*, which was offered in the spring semester of 2020 in the Wadsworth Department of Civil and Environmental Engineering in coordination with the John Chambers Department of Economics and the Reed College of Media in West Virginia University.

## 1. Introduction

In 2013, the Committee on STEM Education, National Science and Technology Council, via its report “Federal Science, Technology, Engineering, and Mathematics (STEM) Education 5-Year Strategic Plan” sounded the first of many alarms calling attention to the need for more engineering graduates in the U.S. [1]. A new global marketplace, unprecedented technological advancements, destabilization of the political world order, and depletion of energy and other strategic resources are among the many global grand challenges that have emerged during the past 10–15 years. To remain a world economic leader, the United States (US) must realize growth in the engineering workforce, and perhaps more importantly, *produce engineers who are more complete in their problem-solving approaches*. However, addressing only the matter of *quantity* will not attend to the increasing *complexity* of 21<sup>st</sup>-century engineering challenges. Indeed, the answers lie in the *quality* of the product as much as, if not more than, the quantity. For centuries, society's problems have been sufficiently linear, mechanistic, and discrete to be served by engineers trained almost exclusively to solve problems through the application of math and science alone. Subsequently, engineers have been deficient in skill sets and disciplines outside these areas [2]. At the same time, to solve the 21<sup>st</sup> century engineering challenges, the training of social scientists that have a more in-depth and comprehensive understanding of the

engineering perspective and methods will also facilitate the cross-disciplinary collaboration needed to address these complex societal challenges.

Perhaps considering the above, some collaborative, cross-disciplinary courses have started being offered in U.S. institutions (see some examples here, [3]), but such courses are not common. The norm remains single-disciplined courses and many opportunities for collaborative cross-disciplinary experiences are missed. For example, civil engineering (CE) capstone courses across the country are cross-disciplinary only to the extent that they may incorporate the CE subdisciplines of structures, transportation, geotechnical, and environmental. Absent are social science perspectives offered by fields outside of engineering. Likewise, it is not common for civil and other engineering programs to offer cross-disciplinary opportunities that reach beyond the collaboration of different engineering schools anywhere in the curriculum.

In this paper, we present the *Holistic Engineering* concept as an approach to address the formation of well-rounded engineers. We also present an application of this concept in a Holistic Engineering Project Course (HEPC) that was designed as a part of a National Science Foundation (NSF) grant (Award Number: 1927232) and was implemented at West Virginia University (WVU). WVU HEPC is developed in such a way that engineering students work with social science students on a complex and open-ended engineering grand challenge problem.

The organization of this paper is as follows. Section 2 discusses the concept of the holistic engineering approach and its key principles. Section 3 presents the structure of the HEPC course and Section 4 presents the implementation of the course in the spring 2020 semester. Finally, Section 5 concludes with key lessons learned and an overview of future teaching and research directions.

## **2. The holistic engineering approach**

Grasso and Martinelli argued that pursuing the concept of the “unity of knowledge” will yield a new definition of engineering which is more fitting for the times ahead [2], [4], [5]. The unity of knowledge is the integration of knowledge across disciplines to deal with complex problems. Many engineering curricula include general education requirements in the form of courses outside of the discipline. However, institutions rarely take the next step and offer connections among these courses to integrate or “unify” students' learning.

The engineering education community has embraced the idea of incorporating multi-disciplinary and cross-disciplinary elements into the curriculum [6]. At the same time, in its Body of Knowledge report, the American Society of Civil Engineers has declared that engineering as a profession must include formal education in such topics as leadership, management, and government [7]. It is noteworthy that these declarations are not in the form of a compendium of courses, but rather as *outcomes* that might be reached through the integration of knowledge. Furthermore, ABET has revised its criteria for engineering programs to be less prescriptive and allow for more flexibility in the curriculum [8], [9].

Motivated by the above, the holistic engineering approach champions the *integration of engineering disciplines with nontechnical disciplines in solving engineering challenges*. As

engineers develop technical/engineering solutions for the society, this approach encourages engineers to seek solutions by incorporating social dimensions in defining the engineering problems and measuring the effectiveness. Thus, future engineers should be equipped with a basic understanding of nontechnical disciplines such as effective/strategic communication and distributive justices to ensure social equity in engineering solutions [2], [4]. While mathematics and science are necessary tools for working with complex systems, so too is an understanding of human nature and interactions with system components [4]. Subsequently, engineers seeking to solve problems with such systems must have a broader, more complete set of tools at their disposal. Formal study and collaboration with people in other fields will go far in developing this broader skill set.

The holistic engineering approach prepares engineers to be more effective in defining the problem with nontechnical skills and tools. For example, transportation engineers often define congestion as a transportation engineering problem and attempt to minimize congestion by adding new facilities (such as additional lanes) which often does not lead to a substantial reduction in congestion. However, if the principle of economics is added in the engineering solution development process, engineers could develop an engineering and economic solution by adding a congestion pricing solution in addition to adding new facilities to manage traffic demand. In another perspective, a civil engineer working alongside a social psychologist would see congestion as not only the delay of vehicles and passengers but also as a form of human anxiety and frustration. The incorporation of psychology would enhance the engineer's "toolbox" and broaden the solution space. So, when the engineer is looking for a solution to congestion resulting from a highway work zone, the engineer would certainly consider optimizing the channelization, but they would also consider enforcing the queue discipline since this is the greatest source of driver frustration and perceived time loss. Holistic engineering is not the elimination or reduction in the technical skill sets, but that rigor is complemented with the ability to think powerfully and critically in the context of many other disciplines. Given that rote engineering tasks can now be easily outsourced, Holistic engineering is an approach that views the profession in a broader context and elevates it to a more prominent role in defining and solving society's greatest challenges.

### **3. Course structure and design**

#### **3.1 Course framework**

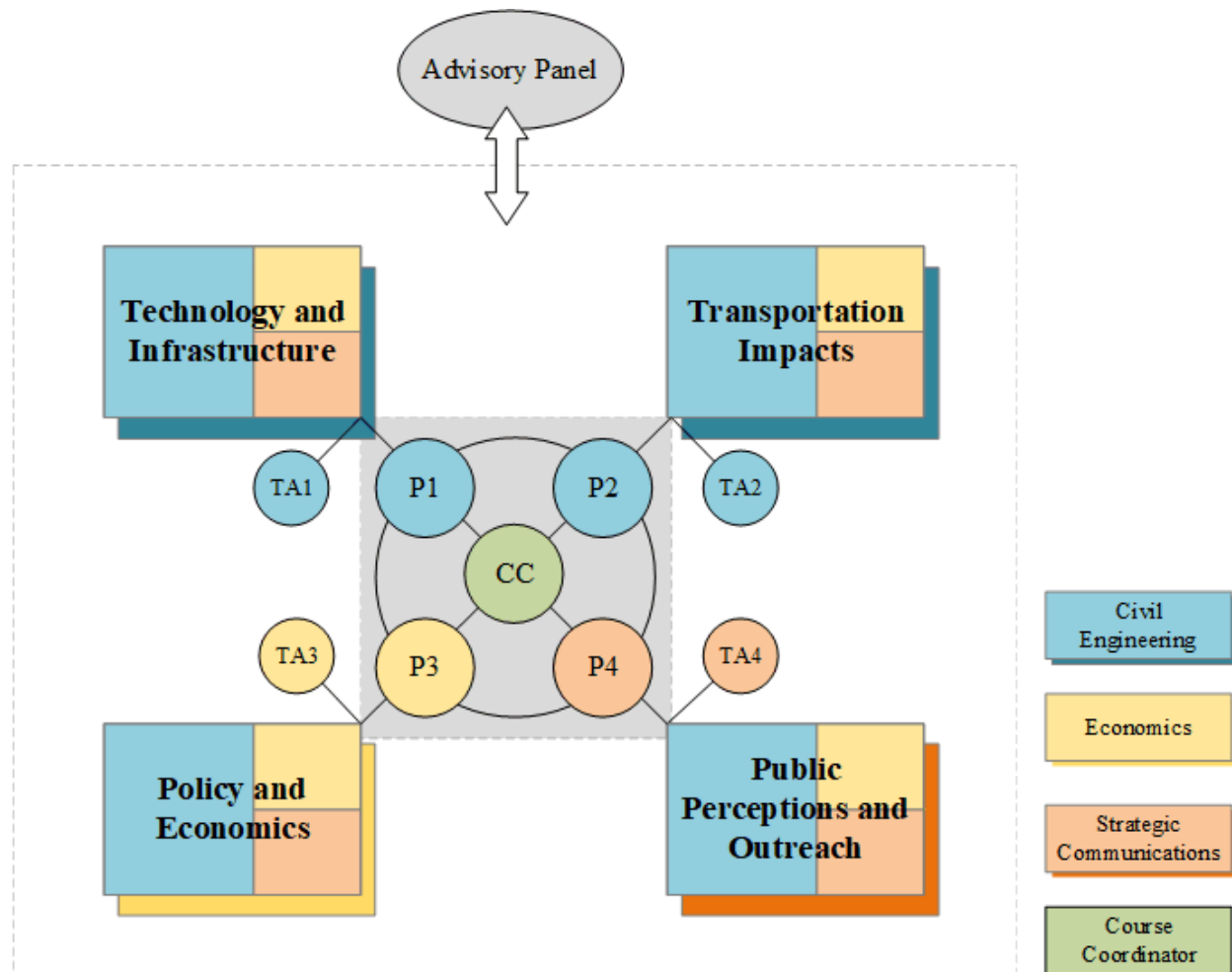
The WVU HEPC course is being developed using the case study of civil engineering with a transportation engineering theme. Recent research has demonstrated that problem-oriented project-based learning is a successful approach to transportation engineering education [10]. Li and Faghri [10] described the benefits of using such an approach as, in part, helping students to realistically evaluate possible transportation approaches and giving them experience and knowledge on multidisciplinary projects. Often, in such an approach, team projects can facilitate learning. In this research, we adopt the holistic engineering approach which requires engineering students to work with individuals with a non-engineering background (e.g., students form strategic communication and economics for the WVU HEPC). Educators from Purdue University have developed a related research program where students from different engineering disciplines worked with a non-profit organization. It was reported that students with different engineering

backgrounds performed as a team. The findings of the program suggested that students developed effective communication skills [11]. Following the suggested team-based framework, in the HEPC offered in spring 2020 at WVU, students from engineering and non-engineering disciplines work in groups on an open-ended and cross-disciplinary engineering problem to study the professional formation of engineers.

Specifically, in the designed HEPC, students work in cross-disciplinary teams from three different areas of study, housed in three different colleges: Civil Engineering, Strategic Communication, and Economics. An important feature of the course is that it centers around a contemporary, complex, open-ended problem that relies on both technical and non-technical perspectives for feasible solutions. Therefore, students from all three areas of study will offer necessary contributions and have access to the skill sets, methods, and perspectives of their counterparts in the other fields. Students engage in a high-level synthesis whereby they add to the topic's body of knowledge through interim reports, a final report, and formal presentations. These deliverables are presented to the course instructors and an outside advisory panel consisting of experts on various aspects of the problem.

The initially proposed offering of the course has a coordinator, two professors from Civil Engineering, one professor from Economics, and one professor from Strategic Communication. Groups are assigned a domain of the problem and all groups have a mix of students from the three fields of study. Figure 1 presents the course organization and the subsequent interactions among the students and professors. Each professor is in charge of guiding one group based on their expertise and background. Apart from the four professors and the coordinator, the expert advisory panel, comprised of professionals representing both the public and private sectors, is also involved with the course and has a double role: (1) they independently evaluate the work of the students, and (2) they are a resource for the students. The course coordinator directly communicates with the professors who supervise the four student groups and ensures that the advisory panel is being actively engaged with the course and will facilitate interaction between the panel, professors and student groups as needed. The course is also supported by teaching assistants.

The five professors in coordination with the advisory panel define the scope of the course. Special attention is paid to identify a theme and related open-ended problem that is timely and relevant to the region's communities. The proposed course theme for the WVU case study and the corresponding problem are *transportation-centered* and involve the *Impacts of Connected and Autonomous Vehicles*. The four student domains include two engineering-centered ones, namely *Technology and Infrastructure* and *Transportation Impacts*, one economics-centered domain, namely *Policy and Economics*, and one strategic communication-centered one, *Public Perception and Outreach*.



**Figure 1.** Illustration of the Holistic Engineering Project Course (HEPC) Structure

The goal is that the four domains complement each other. Below is a description of the domains.

**Engineering:** Two student domains, one that explores technology and infrastructure issues and the other, transportation impacts, applies extensive transportation engineering knowledge, methods, and tools to contribute to the solution of the open-ended engineering problem. Although for this case study, the course mostly involves civil engineering methods and tools integrated with economics and strategic communication, as relates to the theme of Impacts of Connected and Autonomous Vehicles, the following tools are also explored. In the technology and infrastructure domain, students explore electrical, computer, and material engineering solutions, while in the transportation impacts domain, students explore environmental engineering and urban planning concepts and methods. In these two domains, social science students are providing their perspectives on engineering solutions throughout the semester and raising nontechnical questions (e.g., user acceptance of technology) that can help engineering students frame their work in a broader context and incorporate economic, policy and public communication considerations. In addition to producing an improved more comprehensive product for the open-ended engineering problem, engineering students benefit from working with social science students by getting familiar with the professional language of other disciplines and

by practicing communication skills that can help them effectively communicate their work to non-engineering audiences. Social science students benefit from reviewing and supporting engineering work and working alongside engineers to broaden the scope of their work by getting a more in-depth understanding of the technological and engineering constraints of the open-ended engineering problem and the potential solutions.

***Economics:*** Economics offers the students an additional and valuable set of rigorous analytical tools that aid in understanding a wide array of social phenomena that they observe throughout their careers. The example of developing an emissions permit–trading market offers a perfect illustration. Here we face an engineering and economic problem in the form of an inefficiently high level of industrial emissions into the atmosphere. By bringing the economic way of thinking to this problem of external costs, the engineering students can devise an emissions-trading permits system that leads to the societally efficient level of emissions overall, but that also allocates those emissions efficiently over different businesses based on variation in the cost of reducing emissions. In this course, the students are exposed to a situation where engineering and economics come together to achieve a better outcome for society.

Economics also adds several specific problem-solving tools. The first example is cost-benefit analysis: here the students rigorously evaluate the benefits and costs associated with enhancing public infrastructure surround autonomous vehicles. They weigh the required infrastructure investment in a state against various benefits that must be estimated using various economic methods and that require careful consideration over a long time period. Further, the course incorporates an economic evaluation of public policy in terms of understanding the ability of governments to provide infrastructure and several associated challenges in the context of revenue generation. As one additional example, economics can bring the tool of contingent valuation, where engineering students can learn how to carefully evaluate costs and benefits of non-market amenities, such as the value of enhanced safety associated with autonomous vehicles.

***Public and Outreach:*** Even the best-planned and most data-driven innovations in technology, infrastructure, and systems will fall flat without public acceptance. That is, public acceptance (based on various audiences' positive thoughts, feelings, and behaviors regarding related innovations) are essential for adoption and diffusion through society [12]. Strategic communication students, particularly in public relations, public affairs, and public interest communication, are trained to identify and prioritize stakeholders and to develop goal-oriented strategic messaging for key audiences and opinion leaders. Such strategic communication efforts may help bridge the gap between abstract innovation and success in the practical implementation of engineering solutions. Engineering students stand to benefit substantially from exposure to strategic communication professionals' use of social science research methods and models to identify, understand, and persuade key target audiences. This process is nuanced and particularly tricky for generating education and positive engagement surrounding public interest projects that are based on new ideas and/or involve substantial costs, offering learning opportunities not only for the engineering students at the focus of this study but also for the economics and strategic communication students working alongside them.

In sum, the unique structure of the HEPC offers the following features, which facilitates students learning:



1. Students work in teams
2. Students work across disciplines
3. Students work on an open-ended problem
4. Students have access to professors and TAs from multiple disciplines
5. Students have access to external expertise and critique

### **3.2 Course objectives**

The course has been designed to meet several specific educational objectives. Among others, by the end of this course, students should demonstrate their ability to

- Research, develop, analyze, and apply knowledge from across disciplines to formulate and recommend solutions to open-ended problems under time and budgeting constraints.
- Understand, analyze, and evaluate issues of relevance to the project—and identify specific and diversified audiences to incorporate their perspectives and needs surrounding the issue(s).
- Define measurable, realistic, deadline-specific objectives that are appropriate to the project/problem/opportunity scope and timeframe.
- Adhere to and apply professional ethics in developing/implementing plans and practices relevant to the project/problem/opportunity.
- Respectfully and effectively function in multi-disciplinary teams and critically evaluate one's own work and that of others for accuracy, clarity, and fairness.
- Exhibit professionalism through the appropriate use of communications technologies and tools to collaborate with others internal and external to the project.
- “Communicate effectively with a range of audiences” (ABET-3, [13]).
- “Recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts” (ABET-4, [13]).
- “Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives” (ABET-5, [13]).

## **4. Course implementation**

### **4.1 Course platform**

In spring 2020, 21 students enrolled in the course: 12 students from civil engineering, 7 students from strategic communication, and 2 students from economics. The course was offered with the course title “*Technology Innovation: Engineering, Economics, Public Relations.*” For all three colleges, the course was offered as an open elective, and for strategic communication, the course was cross-listed as a capstone. Students enrolled in the strategic communication course had additional educational objectives and were involved in additional educational activities (i.e., conducting research-based strategic communication outreach to increase course enrollment for the following semester).

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For the first offering of the course, the instructors decided not to recruit student in a systematic manner, as we wanted to gauge the innate interest of WVU students of the involved departments and colleges to participate in novel courses like this one. However, to provide students with all the information needed to understand the course purpose and structure, we prepared posters for display in various relevant facilities (see example poster and QR code landing page here <https://enactuswvu.org/nsf-holistic-engineering/>) In addition, the instructors gave short presentations presenting this opportunity to selected undergraduate courses of all three colleges and brief academic advisors about the experience during the registration period of the fall 2019 semester.

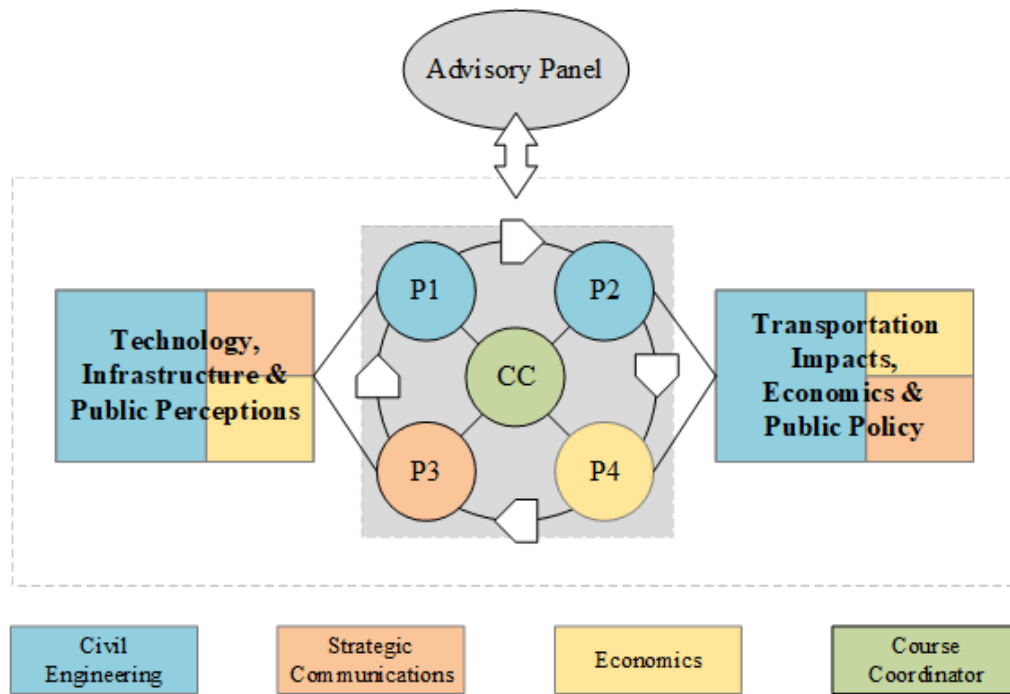
The course design called for multidisciplinary student groups who will work together with five core faculty drawn from engineering, economics, and strategic communication to be established. For the first implementation of the HEPC, two groups were formed instead of four to ensure a cross-disciplinary team while accommodating for the relatively enrollment. One group has been tasked with exploring technology and infrastructure issues and the other is responsible for exploring potential transportation impacts of emerging autonomous vehicles. The two groups were formed to represent two independent committees that comprise a task force. The “Task Force” simulated a real-world task force of experts in engineering, economics, and strategic communication that the West Virginia (WV) Governor’s Office tasked with exploring the future of autonomous vehicles in WV and the implications for the state and recommending planning and policy directions. Below is the description of each committee and tentative areas of focus.

***Technology, Infrastructure, & Public Perceptions Committee:*** Safe and reliable operations of AVs demand substantial modification/retrofitting of the existing transportation infrastructure (such as signs, signals, and related traffic control devices), as well as the installation of advanced traffic control, communications, and big data architecture. In this committee, students critically investigated the technological nature of this challenge, considering economic and social implications. At the stakeholder and user levels, issues of safety, public health, potential system malfunctions, and security threats from hacking and other misuse are central concerns. Thus, in this committee students also identified potential and perceived health and safety, and other public benefits and risks. In doing so, students identified key stakeholders and influencers and developed key messages and communication strategies to make recommendations for public affairs and to enhance likelihood of public acceptance. The tentative areas of focus, as identified by the students in collaboration with the instructions were as follows. In terms of technology and infrastructure, considerations explored were road markings, work zones, broadband infrastructure, vehicle-to-infrastructure communications, road signs, school zones, curb space management, electric vehicle charging infrastructure, traffic signals, digital infrastructure,

parking, and lane width. In terms of public perceptions and public affairs, topics explored were technology acceptance models as they related with AVs (i.e., diffusion of innovations, technology acceptance model, technology acceptance framework), key factors influencing public perceptions of AVs (i.e., level of knowledge; trust in technology; perceived usefulness, ease of use, and advantages over current options; perceived voluntariness of use; AV image and social status; social influence), and key stakeholders/publics and key messages.

**Transportation Impacts, Economics & Public Policy Committee:** The implementation of AVs will have many economic and other societal impacts. Among others, from the household perspective, it is anticipated that vehicle ownership and usage will be affected, and as a result, the traffic flow will change as well. From the commercial perspective, driving occupations will be impacted. As an extension, AVs’ implementation has the potential to reshape the urban, suburban, and rural space. In this committee, students will identify and assess the direct and indirect impacts of AVs’ implementation (such as vehicle ownership and usage, travel time, congestion, safety, employment, environmental, and land use). Students will also discuss public finance considerations and work to formulate key policy questions that will govern the political, financial, and institutional feasibility of implementing AVs. The tentative areas of focus, as identified by the students in collaboration with the instructions were as follows. In terms of transportation impacts, the following impacts were explored: vehicle ownership models, transportation safety, congestion and travel patterns, impacts on alternative modes of transportation, environmental impacts, land use, and parking. In terms of economics and public policy, the following areas were explored: infrastructure cost, current WV spending, potential budgetary shortfalls (AV preparation), gas taxes and alternate revenue sources, potential subsidizations, and cost/benefit analysis.

Figure 2 presents the current course structure.



**Figure 2.** Spring 2020 Course Implementation Structure

## 4.2 Additional perspectives

### *Ethics and distributive justice*

The first course offering incorporated four main disciplines. In addition to the five professors in the three main fields (i.e., engineering, economics, and strategic communication), a professor from the Department of Public Administration with expertise in ethics and distributive justice was involved with the class. The professor gave one lecture and was a resource to the students' work throughout the semester.

It is well understood that technological innovations and engineering advances can have a disruptive effect on the social, political, and economic context [14], [15]. New technologies may favor some over others, may reorder the distribution of resources, reveal conflict over deep-seated beliefs and long-held values, and may involve public policy choices and trade-offs that can have a significant impact. In order to provide an orientation to the ethical, legal, and social implications of new technologies and engineering advances in general and in the specific context of AVs, the course included an interactive plenary lecture on the topic.

The lecture helped the students to understand how past technological-engineering advances have had a disruptive effect that has reordered public attitudes and policy sentiments towards public utilities. Namely, the advent of cellular phone technology was used as an example. This helped to set the context for student reflection and discussion on some of the potential ethical and distribute justice dimensions of AV technology. A simple question was posed to the students to organize some of the broader sociopolitical and economic ramifications of AV development and adoption. To wit: "Do we design AVs to accommodate existing road infrastructure, or do we design roads to accommodate AVs?" This provided the opportunity to discuss how economic and political choices may effect changes in the built environment and influence decisions on public investments in infrastructure. A big "take away" from the session is that the adoption of new technologies often raises age-old questions about equity, justice, individual interest, and the common good.

In addition to investigating broader social, economic, and policy contexts, the session also provided for a brief introduction to recent concerns and discussions about the design of algorithms for AV responses in the face of potential accidents. Algorithm design reflects human value choices. Value choices are not universal, but instead reflect cultural influences and personal preferences. These may reflect preferences for protecting the welfare of the AV occupant over others and the like. These ethical questions have sparked considerable attention with the prospects of AV adoption [16], [17], [18] and have helped to revive and reframe a well-known thought experiment that is especially relevant to engineering. This is the "Trolley Problem" which creates choice dilemmas for valuing human life that take into account utilitarian and other ethics approaches [19]. In this context, "Moral Machine" experiment at MIT has measured value preferences in a group-sourced social experiment [20]. To assist students in their continuing learning, the presentation also included resources for future reference drawn from government, popular, and academic sources. Students were also asked to reflect on lessons learned through a homework assignment.

### ***Panel expertise***

In addition to the instruction from the six faculty, students benefitted from perspectives and feedback from members of a distinguished advisory panel of accomplished professionals and stakeholders of relevance to the disciplines and the project domain. The panel served as an agent of evaluation and a resource to the class. A key element in achieving the HEPC objectives is providing special access and participation of practitioners and diverse stakeholders with expertise relevant to the open-ended problem in the form of an advisory panel.

In the spring 2020 semester, a short mid-semester meeting with the panel provided the students with the opportunity to seek experts' feedback as part of a structured questions and answers session. The goal of the mid-semester meeting with the panel was to make sure that the students can take full advantage of the additional expertise, experience, and valuable guidance that the panel members can provide. The sectors and organizations that were represented on the panel in spring 2020 included local and state governments, the Chamber of Commerce, engineering and PR firms, industry, and researchers with diverse backgrounds and responsibilities. In addition to the mid-semester meeting, several members of the panel were involved with the course throughout the semester and provided their inputs to the class.

### **4.3 Assessment and grading**

Students are graded on both their contribution to their working group and on the quality of their project deliverables. The instructors use materials submitted throughout the course, interactions with the student, and peer evaluations and self-reports as the basis for mid-term and final grades. Several items such as weekly work logs are formally assigned, but other demonstrations of work are also considered as itemized below.

*Final deliverables:* Committee and task force reports and task force presentations (35%): The quality of the final report and presentations will be assessed relative to the project and course objectives. Emphasis is placed on the professionalism and quality of the materials delivered and the response of the Advisory Panel.

*Weekly work log (15%):* This course requires each member of the project to work individually and as part of the overall group and in subgroups. For the students' individual accountability, each member of the class is required to keep a running weekly work log that will document accomplishments over the semester. The work log content should at a minimum include the students' relevant activities, contributions, and work products of the week. The students should also include how much time they spent on those items, and what they anticipate the upcoming week's work to include.

*Interim Committee Presentations (25%):* At some full class meetings, groups give a 5-10 minutes presentation on their progress and plans for the next week, followed by Q&A to ensure integration and collaboration across teams. Groups should rotate presenters throughout the semester.

*Self and Peer evaluations (10%):* Every student is required to complete four evaluations of themselves and peers. The most significant criteria are contributions to the work and professionalism.

*Class Engagement (15%):* Students participate in take-home assignments, in-class activities, etc. designed to get everyone up to speed on the topic and in sync with skills and expectations.

#### 4.4 Logistics

Figure 3 presents the tentative schedule of the course offering. As can be seen in the schedule, the class is scheduled to spend the first four weeks discussing background information, knowledge, and methods drawn from all three disciplines. Subsequent weeks allow the teams to work on the project and accommodate presentations during which the teams can receive feedback from all instructors and fellow students of the other team. One guest lecture on the topic of ethics and distributive justice is also scheduled and time for additional guest speakers from the panel is included. The mid-semester meeting with the panel is also included.

		<b>Class Overview</b>	<b>Deliverables Due</b>
Wk1	1/14	PLENARY SESSION: Intro & Icebreakers	
	1/16	PLENARY SESSION: Project Topic and Class Structure	
Wk2	1/21	PLENARY SESSION: Engineering Introductions	Committee Application
	1/23	PLENARY SESSION: Economics & Strategic Communication Introductions	Weekly Log (WL)
Wk3	1/28	PLENARY SESSION: Technology and Infrastructure <i>Homework #1 (Engr) Assigned</i>	
	1/30	PLENARY SESSION: Transportation Scenarios and Impacts <i>Homework #2 (Engr) Assigned</i>	WL, HW #1
Wk4	2/4	PLENARY SESSION: Public Finance and Policies <i>Homework #3 (Econ) Assigned</i>	HW #2
	2/6	PLENARY SESSION: Identifying Audiences and Influencing Attitudes and Behaviors <i>Homework #4 (STCM) Assigned</i>	WL, HW #3
Wk5	2/11	WORKING SESSION	HW #4
	2/13	WORKING SESSION	WL
Wk6	2/18	PLENARY SESSION: Ethics & Distributive Justice <i>Homework #5 (Ethics) Assigned</i>	
	2/20	WORKING SESSION	WL, HW #5
Wk7	2/25	WORKING SESSION	
	2/27	WORKING SESSION	WL
Wk8	3/3	PLENARY SESSION: Committee on Technology, Infrastructure and Public Perceptions- Informal Presentations	Committee 1 Presentation
	3/5	PLENARY SESSION: Committee on Transportation Impacts, Finance and Policy - Informal Presentations	WL, Committee 2 Presentation
Wk9	3/10	WORKING SESSION	
	3/12	PLENARY SESSION: Presentation to the Advisory Panel	WL
Wk10	3/17	SPRING RECESS	
	3/19		
Wk11	3/24	WORKING SESSION	
	3/26	PLENARY SESSION: Guest Speaker	WL
Wk12	3/31	WORKING SESSION	
	4/2	WORKING SESSION	WL
Wk13	4/7	PLENARY SESSION: Committees' Presentations - Feedback	Committees' Presentations
	4/9	PLENARY SESSION: Work on Task Force Presentation	WL
Wk14	4/14	PLENARY SESSION: Work on Task Force Presentation	Final Committee Reports
	4/16	PLENARY SESSION: Task Force Presentations - Feedback	WL, Task Force Presentation Draft
Wk15	4/21	PLENARY SESSION: Task Force Presentation Dress Rehearsal	Final Task Force Presentation
	4/23	PLENARY SESSION: Final Task Force Presentation to Advisory Panel	WL
Wk16	4/28	PLENARY WORKING SESSION: Final Report Wrap-Up	Task Force Report Draft
	4/30	PLENARY SESSION: Debriefing (Final Class)	Final WL, Final Task Force Report, Peer Reviews/Self-Evaluation
	5/4-8	Celebrate!	

**Figure 3.** Tentative Schedule

## 5. Overview and future directions

This paper discussed the holistic engineering approach to engineering education and presented a novel course that has been developed at West Virginia University and offered in the Wadsworth Department of Civil and Environmental Engineering in coordination with the John Chambers Department of Economics and the Reed College of Media in West Virginia University. NSF supported the instructors to develop, implement, and evaluate the effectiveness of the HEPC.

In the first course offering, five core instructors were involved with the course (three from the Civil and Environmental Engineering Department and two from the Department of Economics and the College of Media respectively). An additional professor from the Department of Public Administration was also consistently involved throughout the semester. Finally, a panel consisting of several individuals with diverse backgrounds and responsibilities representing local and state governments, the Chamber of Commerce, engineering and PR firms, industry, and researchers provided additional guidance and resources to the students. Students in this course were engaged in a comprehensive shared problem-solving learning experience, specifically exploring the future of autonomous vehicles in WV and the implications for the state and recommending planning and policy directions.

At this stage of the design and implementation of the course, the course structure is re-evaluated and the structure for the second offering is refined. Generally, the course had lower enrollment than planned. However, that was somewhat anticipated because of the experimental nature of this course and the fact that this was the first offering. The enrollment was especially low for the College of Business and Economics. Just before the beginning of the semester, informal student feedback was obtained from economics students regarding their low interest in participating in this class. All students mentioned that the class time and class meeting location distance from their college was an issue. WVU has three campuses; the course was offered in the Evansdale Campus, while the College of Business and Economics is housed in the Downtown Campus, about 30 mins commute time depending on traffic condition. In addition to the transportation time required between campuses, Engineering courses are scheduled at different intervals than Economic courses. Therefore, the economic students would be unable to attend any other mid- or late-day courses if they were enrolled in this course. To address these issues, the course for fall 2020 was scheduled to be a late course (3:30-4:45 PM, on Tuesdays and Thursdays). From the Media college perspective, although a capstone offering adds logistical complications and additional responsibilities of the instructors to meet additional educational objectives, it was found that having the course cross-listed as a capstone was an effective way of attracting a higher number of students. Therefore, to ensure good participation of Media College students, the plan is that the course will be offered as one of the alternative capstone courses offered in the Media College for fall 2020. Furthermore, as part of the capstone responsibilities, in spring 2020, media students are promoting the course to other engineering and non-engineering students on both campuses by developing a recruitment video.

To evaluate the effectiveness of the HEPC, data collection has been started in the spring 2020 course and will continue in the Fall 2020 course. The data analysis explores the impact of the proposed platform on the formation of engineering identity. An initial evaluation of the data has

been included in Dey et al. [21]. The analysis will be completed upon the conclusion of the second offering of the course.

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## 7. References

- [1] The Committee on STEM Education, National Science and Technology Council (NSTC), “Federal Science, Technology, Engineering, and Mathematics (STEM) education 5-Year strategic plan,” 2013. Available: [https://www.whitehouse.gov/sites/default/files/microsites/ostp/stem\\_stratplan\\_2013.pdf](https://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf). [Accessed January 2020].
- [2] T. Litzinger, L. R. Lattuca, R. Hadgraft, and W. Newstetter, “Engineering education and the development of expertise,” *Journal of Engineering Education*, vol. 100(1), pp. 123-150, 2011.
- [3] American Society for Engineering Education (ASEE), “Engineering enhanced liberal education project, case studies,” 2018. Available: <https://www.asee.org/engineering-enhanced-liberal-education-project/case-studies>. [Accessed Jan. 2020].
- [4] D. Grasso, and D. R. Martinelli, “Holistic engineering,” *Chronical of Higher Education*, pp. B8-B9, 2007.
- [5] E. Wilson, *Consilience: The Unity of Knowledge*. Randomhouse, 1998.
- [6] R. Anderson, T. Schweisinger, and J. Martin, “Multidisciplinary research projects as a pathway for undergraduate skill development: A pilot study,” *Graduate Research and Discovery Symposium (GRADS)*, 2015.
- [7] American Society of Civil Engineers (ASCE), “Civil engineering body of knowledge for the 21st century: preparing the civil engineer for the future,” 2008.
- [8] ABET, “Criteria for accrediting engineering programs 2016-2017,” *Baltimore, MD: ABET Engineering Accreditation Committee*, 2015.
- [9] ABET, “Engineering criteria 2000 (EC2000),” *Baltimore, MD: ABET Engineering Accreditation Committee*, 1995.
- [10] M. Li and A. Faghri, “Applying problem-oriented and project-based learning in a transportation engineering course,” *Journal of professional issues in engineering education and practice*, vol. 142(3), 2016.



- [11] E. J. Coyle, L. H. Jamieson, and W. C. Oakes, "EPICS: Engineering Projects in Community Service," *International Journal of Engineering Education*, vol. 21(1), 2005.
- [12] E. Rogers, *Diffusion of Innovations* (5th ed.). New York, NY: Simon & Schuster, Inc, 2003.
- [13] ABET, "Criteria for accrediting engineering programs 2020-2021," Baltimore, MD: ABET Engineering Accreditation Committee, 2019.
- [14] D. Edgerton, *The Shock of the Old: Technology and Global History since 1900*. New York: Oxford University Press, 2007.
- [15] C. R. Morris, *The Dawn of Innovation*. New York: Public Affairs, 2012.
- [16] J. Fleetwood, "Public health, ethics, and autonomous vehicles." *American Journal of Public Health*, vol. 107(4), pp 532-537, 2017.
- [17] C. Lester, "A study on driverless-car ethics offers a troubling look into our values," *The New Yorker*, 2019. Available: <https://www.newyorker.com/science/elements/a-study-on-driverless-car-ethics-offers-a-troubling-look-into-our-values>. [Accessed January 2020].
- [18] P. Lin, "The ethics of autonomous cars," *The Atlantic*, 2013. Available: <https://www.theatlantic.com/technology/archive/2013/10/the-ethics-of-autonomous-cars/280360/>. [Accessed January 2020].
- [19] H. M. Roff, "The folly of trolleys: Ethical challenges and autonomous vehicles." *The Brookings Institution*, 2018. Available: <https://www.brookings.edu/research/the-folly-of-trolleys-ethical-challenges-and-autonomous-vehicles/>. [Accessed January 2020].
- [20] Y. E. Bigman and K. Gray, "Life and death decisions of autonomous vehicles," *Nature*, vol. 579(7797), pp. E1-E2, 2020.
- [21] Dey et al., "Development of a holistic cross-disciplinary project course experience as a research platform for the professional formation of engineers," in *2020 ASEE Annual Conference and Exposition, Montreal, Quebec, Canada*, 2020.